ON THE EDGE STRUCTURE OF A HELIAS CONFIGURATION

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INTRODUCTION . The next step in the Garching stellarator programme, the experiment WENDELSTEIN VII-X, will use a Helias configuration (Helical Advanced Stellarator) with 5 field periods, aspect ratio about 10, major radius of 6.5 m, and magnetic fields up to 3 T. One of the aims of this optimized stellarator experiment is the operation at elevated average beta values of ≈ 5% . To reach this goal, a heating power of the order of 20 MW is necessary. This poses challenging tasks in application and removal, especially to attain a low level of impurities. The complex physics of the edge plasma, depending on internal transport processes and on effects at the plasma boundary, and the necessity of sufficient impurity control for long-pulse experiments call for knowledge of the edge structure of the magnetic topology. The edge structure is influenced by the value of the rotational transform, and by the shape of the first wall and/or the position of limiter(s). In the present investigation vacuum magnetic fields are used. This approach is justified since Helias systems have small changes of their magnetic surfaces and rotational transform profiles with beta.

VACUUM FIELD AND LIMITERS . For the present investigation the Helias system HS 5–7 is used. This configuration is similar to that described in [1], with the major difference that the edge value of the rotational transform is $\iota_a = 1$ with five associated magnetic islands, see Fig. 1 . One can anticipate to use such islands for plasma edge control. The separatrix region is 'ergodic' with some radial extension. Two tentative limiters, options A and B, are indicated in the left part of the figure: a bulged system on

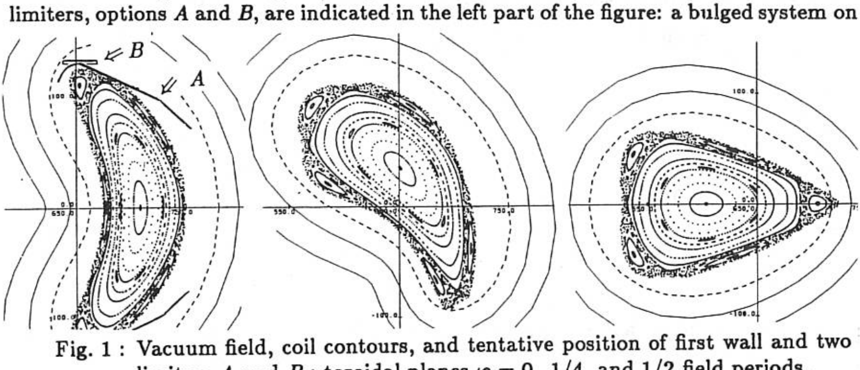

Fig. 1 : Vacuum field, coil contours, and tentative position of first wall and two limiters A and B ; toroidal planes $\varphi = 0$, 1/4, and 1/2 field periods.

[1] C. Beidler et al., paper P 2 B 5 , this conference.

top and bottom near the X-point, shaped smoothly towards the first wall at $\varphi \approx \pm 10^o$, and a plate at $Z = 1.3$ m with radial width $\delta R = 0.3$ m, extended between $\varphi = -3^o$ and 12^o. The magnetic topology and the limiter systems are toroidally fivefold periodic.

Fig. 2 is a close-up of the magnetic topology. Three irrational flux surfaces, with one rational surface $\iota = 15/16$ in between are shown, and the ι = 1-island . It has an internal transform of $\iota_i \approx 1/7$, and a cluster of 8 sub-islands near its edge. The island and the ergodic region partially intersect the first wall between $\varphi \approx 20$ and 52^o , which is neglected in the calculation. The position of the separatrix, especially of its X-points, depends weakly on the step length of field line integration, $\delta s = 2$ to 5 cm. The radial extension of the ergodic region is uncertain, it may be enlarged by effects of the finite grid size of stored field values used for fast integration. Up to 1500 transits are calculated in this region; it may be 'open'.

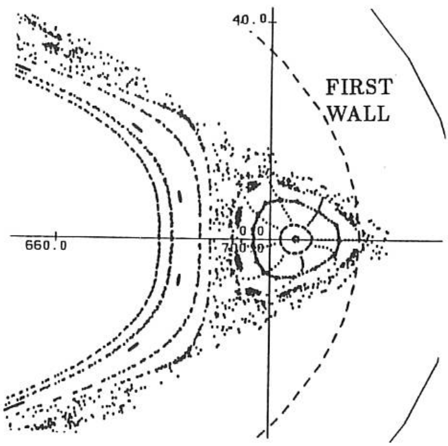

Fig. 2 : Detail of Fig. 1 at $\varphi = 36^o$.

Other magnetic topologies with irrational or rational values of the rotational transform at the edge can be produced by superposed toroidal and/or vertical fields. Limiter or separatrix dominated configurations are to be distinguished. At rational ι-values at the edge, perturbation fields may play an essential role. In cases with an irrational ι-value at the edge, the transition from closed to open topology is comparatively sharp; a substantial radial extension of an ergodic layer can be questioned.

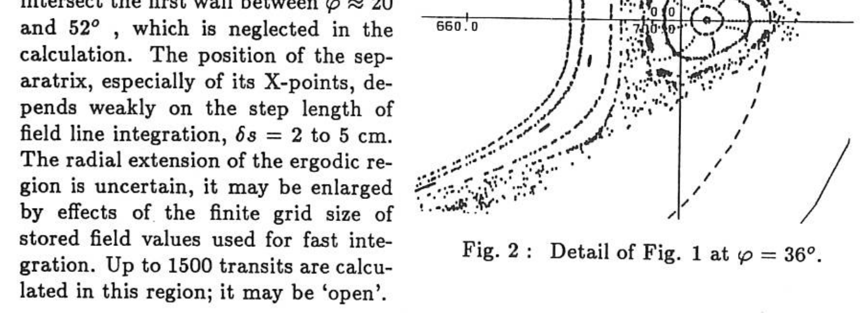

Fig. 3 : Example of a 2×8 field lines, started in the vicinity of an X-point, intersecting with first wall or limiter A after 3 to 66 transits.

EDGE STRUCTURE . The edge structure of the vacuum fields in HS 5–7 and the intersection with first wall and/or limiter is studied by following magnetic field lines started near the separatrix, in many cases near one of its X-points, at chosen toroidal and poloidal angles. The integration is done in both directions, parallel and opposite to $\vec{B}$. An example is given in Fig. 3 , where 2×8 field lines, started in the vicinity of an X-point within $\delta R = 2.5$ and $\delta Z = 1$ cm perform 3 to 66 transits around the torus. Nearly all of these field lines hit the limiter type A ; the first wall is reached after one additional transit by all 16 field lines. Four other neighbouring field lines remain after 120 transits at distances of 7 to 8 cm from the wall, and 2 cm from limiter A, respectively. Low transit numbers, typically 2 to 10 until intersection, are seen for starting points within the ergodic layer. Large transit numbers, up to more than 400 , are seen at starting points close to the X-point; these field lines leave the separatrix region always near an X-point and intersect, within one or two additional transits, with the first wall or with limiter A . In these integrations a comparatively short step length, $\delta s = 2$ cm, is required. In summary: comparatively well defined 'fans' of escaping field lines exist in HS 5–7 , and the ergodicity of the separatrix region is not effective.

HOT SPOT PATTERNS . The intersection points with the wall or with limiter A are shown in Figures 4 and 5. The pattern of the intersection points differs markedly. In Fig. 4, two 'hot spots' are seen near $\varphi = 3/8$ and $5/8$ field periods. For the whole torus a total hot spot area of about 1 m^2 is estimated. In Fig. 5, about half of the field lines end at the limiter bulges in narrow stripes. Most of them are started near one of the X-points at various toroidal and poloidal positions. In other tests 10 starting points are used at equal poloidal angles for 13 toroidal positions; the radial coordinate is extrapolated from inner magnetic surfaces. These starting points are mainly in the ergodic region.

Fig. 6 shows the connection of the wall to the limiter type B , and to points started 5 cm below it. Since this limiter is positioned outside of the separatrix, there is no direct connection, and only some part of the field lines started 5 cm below this limiter reaches the vicinity of the separatrix.

LENGTH OF FIELD LINES . A large span of the lengths of field lines is seen in the above investigations. For starting points outside the ergodic region small values of the length of a field line from wall to wall, L_{ww}, are observed, ranging between less than the length of a field period, $L_p = 8.6$ m, up to a few times this value. Towards the separatrix and close to it, up to several hundreds of transits around the machine, corresponding to values of L_{ww} up to 29 km have been seen; most of the data range between 100 and 500 m. Slightly shorter values are obtained for the limiter A as for the first wall. Field lines started inside the separatrix (and therefore not touching the wall) can be followed numerically up to ±1500 transits around the machine, corresponding to a total length up to about ±65 km; they attain a minimum distance of about 10 cm to the wall, and about 4 cm to the limiter A . Elements of limiter B are connected to the wall by field lines ranging between about 1 and 27 m in length. If this limiter is shifted by 5 cm downwards, local maximum values up to 350 m are seen.

SUMMARY AND CONCLUSIONS . The conditions at the edge of HS 5–7 are dominated by the proximity of the first wall in the range between $\varphi = 3/8$ and $5/8$ field periods. Some ergodicity is seen at the separatrix for $\iota_a = 1$. At this rational ι-value 5 magnetic islands are present. They are partially intersected by the first wall. There, an inhomogeneous pattern of the intersection points of field lines started close to the separatrix is seen, from which a total 'hot spot' area of the order of 1 m^2 is estimated. Due to the comparatively low transit numbers of most field lines the finite radial extension of the ergodic region cannot be utilized to increase this area. – Two tentative limiter shapes are studied which collect some part of the field lines emerging outside of the separatrix. Further refinements in geometry of first wall and limiter are in progress.

Fig. 4 : Angular plot of intersection points with first wall. Abscissa = 1 field period.

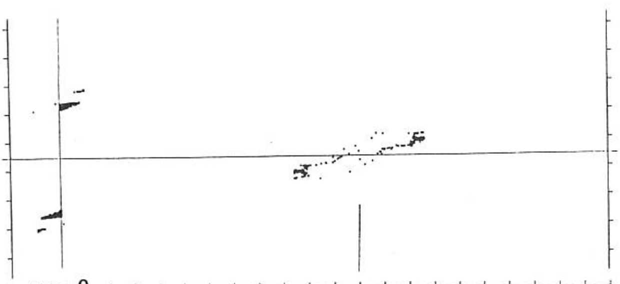

Fig. 5 : As above, limiter type *A* .

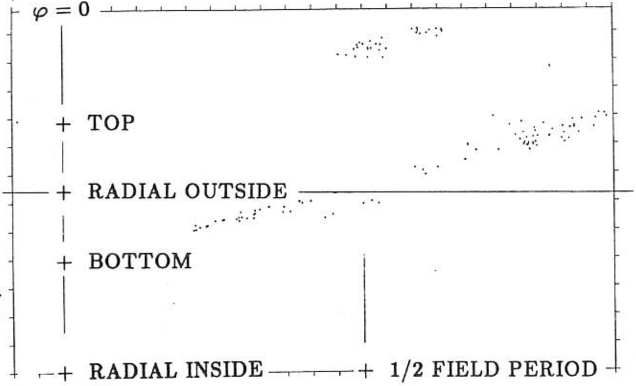

Fig. 6 : Intersection points at first wall; field lines started from limiter type *B* and 5 cm downwards.